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EVALUATION OF ARONETICS TWO-PHASE JET SCRUBBER

Joseph D. McCain

Southern Research Institute

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December 1974

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The report gives results of fractional and overall mass efficiency tests of the Aronetics two-phase jet scrubber. The tests were performed on a full scale scrubber used for controlling particulate emissions from a ferroalloy electric arc furnace. Total flue gas particulate mass concentrations were determined at the inlet and outlet of the scrubber by conventional (Method 5) techniques. Inlet and outlet particulate concentrations as functions of size were determined on a mass basis using cascade impactors for sizes of about 0.3-5 μm, and on a number basis for sizes smaller than about 1 μm using optical and diffusional methods. The report includes brief descriptions of the ferroalloy furnace process, the Aronetics scrubber, economics of operating the scrubber, measurement methods for determining fractional efficiency, a time history of the furnace particulate emissions, and measured fractional efficiencies.

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ABSTRACT

This report presents the results of fractional and overall mass efficiency tests of the Aronetics, Inc., Two Phase Jet Scrubber. The tests were performed on a full scale scrubber used for controlling particulate emissions from a ferro-alloy electric arc furnace. Total flue gas particulate mass concentrations were determined at the inlet and outlet of the scrubber by conventional (Method 5) techniques. Inlet and outlet particulate concentrations as functions of size were determined on a mass basis using cascade impactors for sizes from about 0.3 μm to 5 μm, and on a number basis for sizes smaller than about 1 μm using optical and diffusional methods.

The text of this report includes brief descriptions of the ferro-alloy furnace process, the Aronetics Scrubber, economics of operating the scrubber, the measurement methods for determining the fractional efficiency, a time history of the furnace particulate emissions, and measured fractional efficiencies.

This report was submitted in partial fulfillment of Contract 68-02-1480 to Southern Research Institute under the sponsorship of the Environmental Protection Agency. The work reported here was completed November 30, 1974.

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SECTION I

CONCLUSIONS

The collection efficiency of the Aronetics Two Phase Scrubber determined by conventional (Method 5) techniques on a source producing particulate having a mass mean diameter of about 3 μm was 95.1 and 96.7% for two days of testing. Measured fractional efficiencies were about 70% at 0.01 μm, about 35% at 0.05 μm, 35% at 0.1 μm, 99% at 0.5 μm, 99% at 1 μm, and 99.4% at 5 μm. The scrubber energy usage during the tests was approximately 635 JOULES/1000 SCM (17000 BTU/1000 SCF) at a net pressure rise of 12½ to 16 in. H_2O. This energy usage was a result of using all the process waste heat available and may have been in excess of the minimum amount required to achieve the efficiencies obtained during these tests.

SECTION II

INTRODUCTION

This report presents results of tests conducted by Southern Research Institute to determine the capability of the Aronetics, Inc., Two Phase Jet Scrubber to collect fine particulates. The goals of the tests were: (1) to determine optimum operating conditions of the scrubber, (2) to determine the overall mass efficiency and the fractional efficiency of the scrubber while operating under optimum conditions, and (3) to determine the fractional efficiency of the scrubber for some non-optimum operating conditions as time and circumstances permitted. Figure 1 is a schematic of the basic furnace and scrubber system showing the inlet and outlet sampling locations.

The tests were conducted on a 7.5 MW submerged arc ferro-alloy furnace at Chromasco, Inc.'s Memphis, Tennessee facility. The furnace was operating continuously 24 hours per day, producing approximately 31 metric tons/day of ferrochrome. The furnace was tapped at approximate 2 hour intervals with several charging and stoking operations taking place at irregular intervals between each consecutive tap. The actual timing for any one furnace cycle varied somewhat from the nominal 120 minute tap cycle. The operations for any one batch were: (1) charging of the furnace with ore, coke, remelt, and gravel

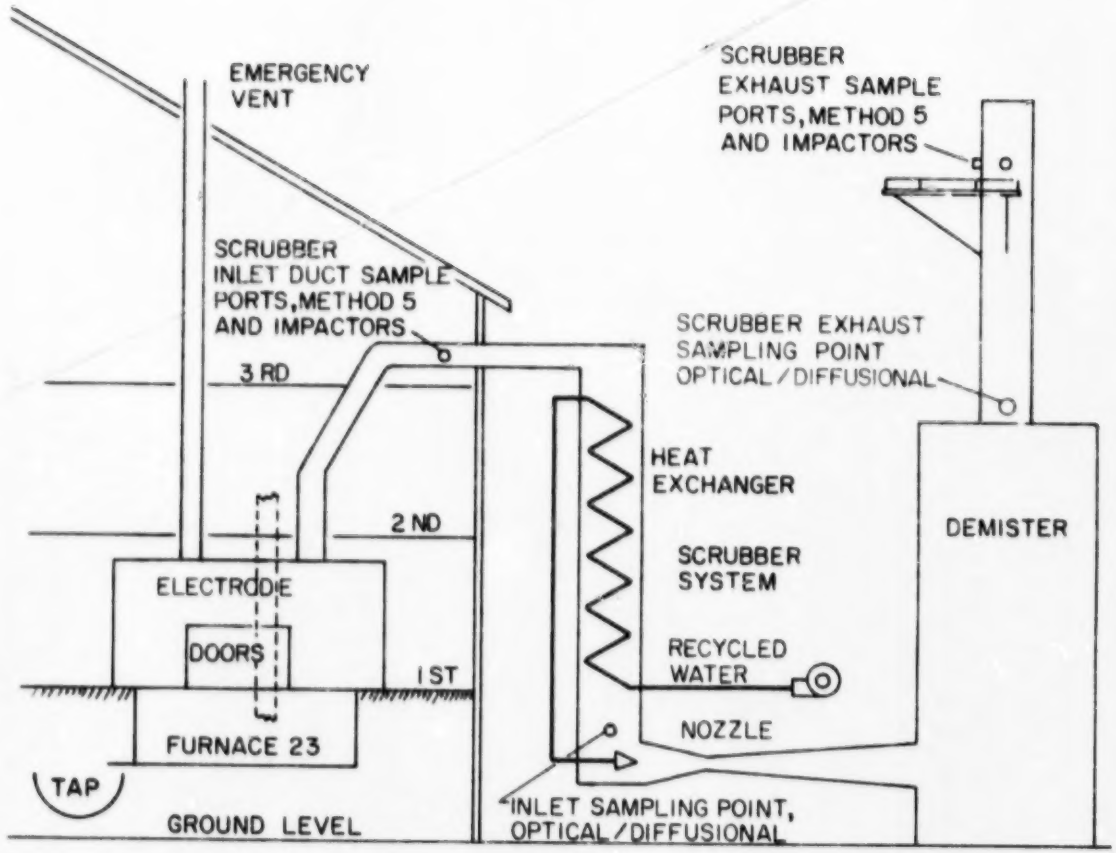
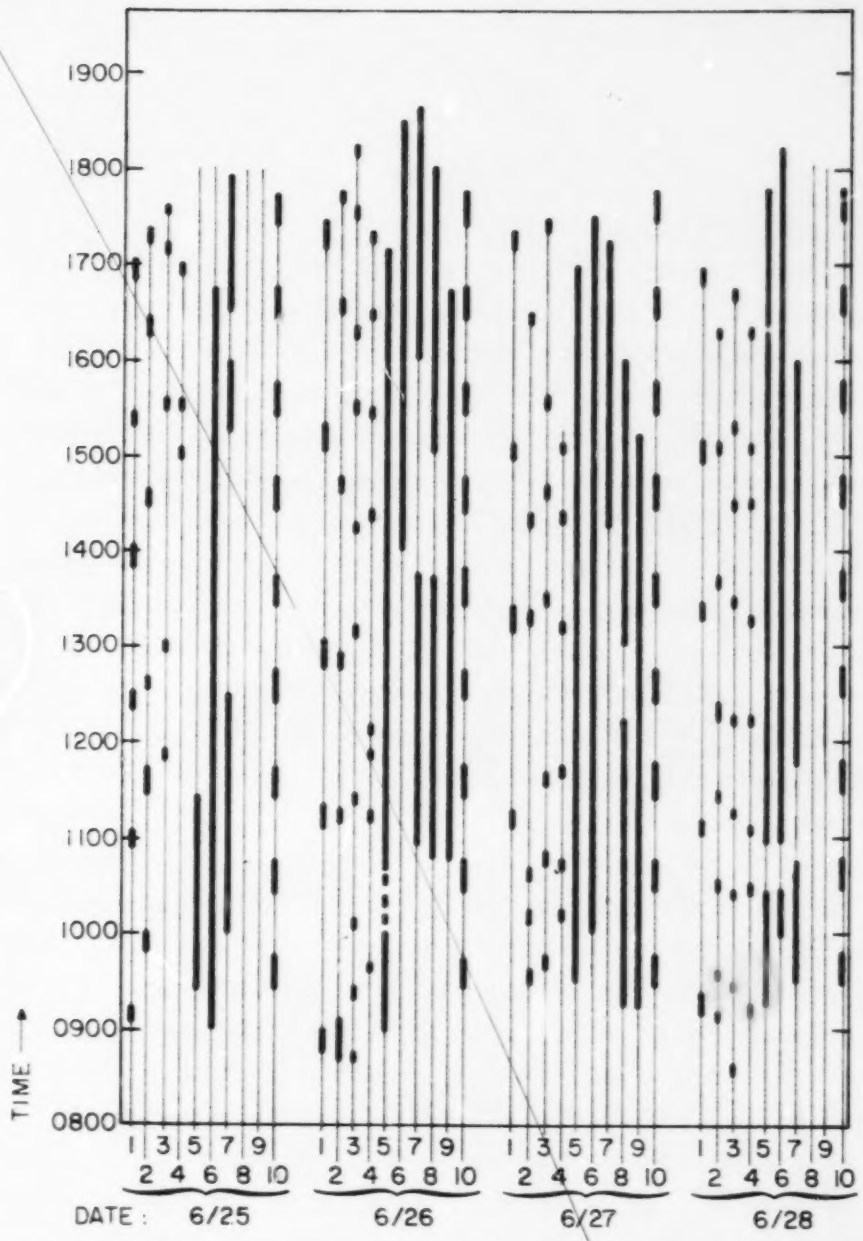


Figure 1. General layout of furnace and scrubber system showing sampling locations.

requiring about 10% of the time for one tap cycle; (2) stoking, requiring about 8% of the time over one tap cycle, and (3) tapping, requiring about 12% of the cycle. Figure 2 shows the time periods during which the various furnace, scrubber, and measurement operations took place during the four days of testing.

The highest particulate emission rates occur during the tapping portion of the operation, with the actual emission rate and size distribution of the particulate being quite variable throughout the cycle. This variability caused some difficulty in both measurement and interpretation of data as is described in the discussion section of this report.

The waste process gases, at temperatures of about 920°K (1200°F) from the furnace, are carried through a duct to a heat exchanger which supplies approximately 480°K (400°F) high pressure water to drive the scrubber and provide the necessary system draft. The gas temperature leaving the heat exchanger is about 380°K (220°F). The draft for the entire furnace and scrubber system is provided by the two phase jet in the scrubber module. During operation, the scrubber produces a net pressure rise from inlet to outlet of 31.8 cm water gauge (12.5 in. H_2O) at a gas flow of 227 kg/min (500 lbs/min) and 40.6 cm water gauge (16 in. H_2O) at a gas flow of 250 kg/min (550 lbs/min). Typical volumetric gas flow rates were about 197 m^3/min (6944 SCFM) during these tests. A description of the operation of the scrubber is given in Appendix A.



1 - TAP FURNACE
2 - CHARGE FURNACE
3 - STOKE FURNACE
4 - INLET IMPACTOR SAMPLING
5 - OUTLET IMPACTOR SAMPLING
6 - OUTLET IMPACTOR SAMPLING
7 - OPTICAL/DIFFUSIONAL SAMPLING 25/26 OUTLET 27/28 INLET
8 - INLET MASS SAMPLING
9 - OUTLET MASS SAMPLING
10 - HEAT EXCHANGER SOOT BLOWING

Figure 2. Daily record of furnace and scrubber operations and sampling periods.

SECTION III

DISCUSSION

A total of four measurement techniques were used during the tests. These were: (1) diffusional techniques using condensation nuclei counters and diffusion batteries for determining concentration and size distribution on a number basis for particles having diameters less than approximately 0.2 μm, (2) optical techniques to determine concentrations and size distribution for particles having diameters between approximately 0.3 μm and 1.5 μm, (3) inertial techniques using cascade impactors for determining concentrations and size distributions on a mass basis for particles having diameters between approximately 0.25 μm and 5 μm, and (4) standard mass train measurements for determining total inlet and outlet mass loadings.

The useful concentration ranges of both the optical counter and the condensation nuclei counters are such that extensive dilution of the gas streams being sampled was required. Dilution factors of about 65:1 were used for both inlet and outlet measurements. In order to insure that condensation effects were minimal and that the particles were dry as measured, the diluent air was dried and filtered, and diffusional driers were utilized in the lines carrying the diluted samples to the various instruments.

Because of the size and complexity of the optical and diffusional measuring systems, and the fact that only one set of equipment was available for measurements of this type, it was not possible to obtain simultaneous inlet and outlet data with these methods. The system was first installed at the outlet sampling location, where an attempt was made to tune the scrubber and all the outlet data were obtained. Subsequently, the equipment was moved to the inlet and the necessary inlet data were obtained. For the purposes of calculating the efficiency of the scrubber, the assumption was made that the furnace process was sufficiently repetitive that the inlet data, as obtained above, were a valid representation of that which would have been obtained during the time the outlet measurements were made. Accuracy in the diffusional measurements was limited by process variations and the efficiencies derived from these data are somewhat uncertain. However, the trends in the fractional efficiencies derived from the data are probably real and the fractions of the influent material that penetrate the scrubber are probably correct to within a factor of two.

The optical data are presented on the basis of equivalent polystyrene latex sizes and the indicated sizes can differ from the true sizes by factors as large as two to three. Data obtained using this method were primarily intended as a means of real time monitoring of process changes and the results of

changes in the scrubber operation, but also serve as rough checks on the data obtained with the cascade impactors. A partial check of the optical sizing was done using a dynamic sedimentation method, with reasonable agreement being found between diameters based on settling velocities and the optical diameters. The sampling system used for obtaining the optical and diffusional data is illustrated diagrammatically in Figure 3.

The tests took place on the dates of June 24 through June 28, 1974, with June 24 primarily used for instrumentation setup, checkout, and preliminary measurements. Attempts at optimizing the scrubber operating parameters were made on June 25 using the optical and condensation nuclei counters. A combination of a long heat exchanger time constant and rapid furnace condition changes made it impractical to optimize the scrubber operating parameters within the time available. Therefore the scrubber conditions were set by a representative of the manufacturer on the basis of past experience with the system.

Figures 4 and 5 show records made at the scrubber inlet using the optical and diffusional systems. Figure 4 is condensation nuclei/diffusion battery data which correspond to particulate concentrations for particles having diameters larger than .01 and .06 μm, respectively. These data were taken over a 105 minute period on June 28 and cover an interval of time corresponding roughly to a typical furnace

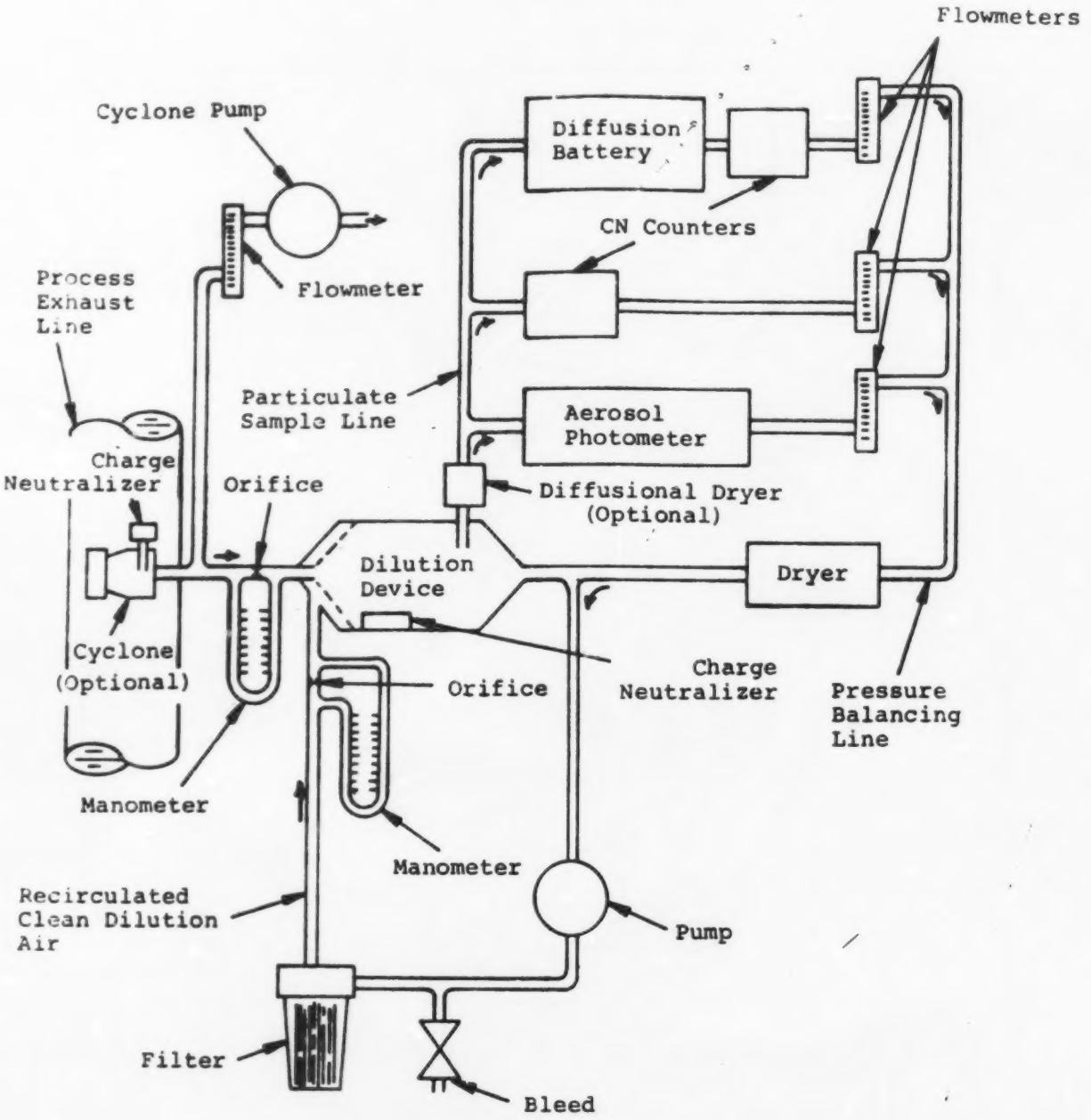


Figure 3. Optical and Diffusional Sizing System

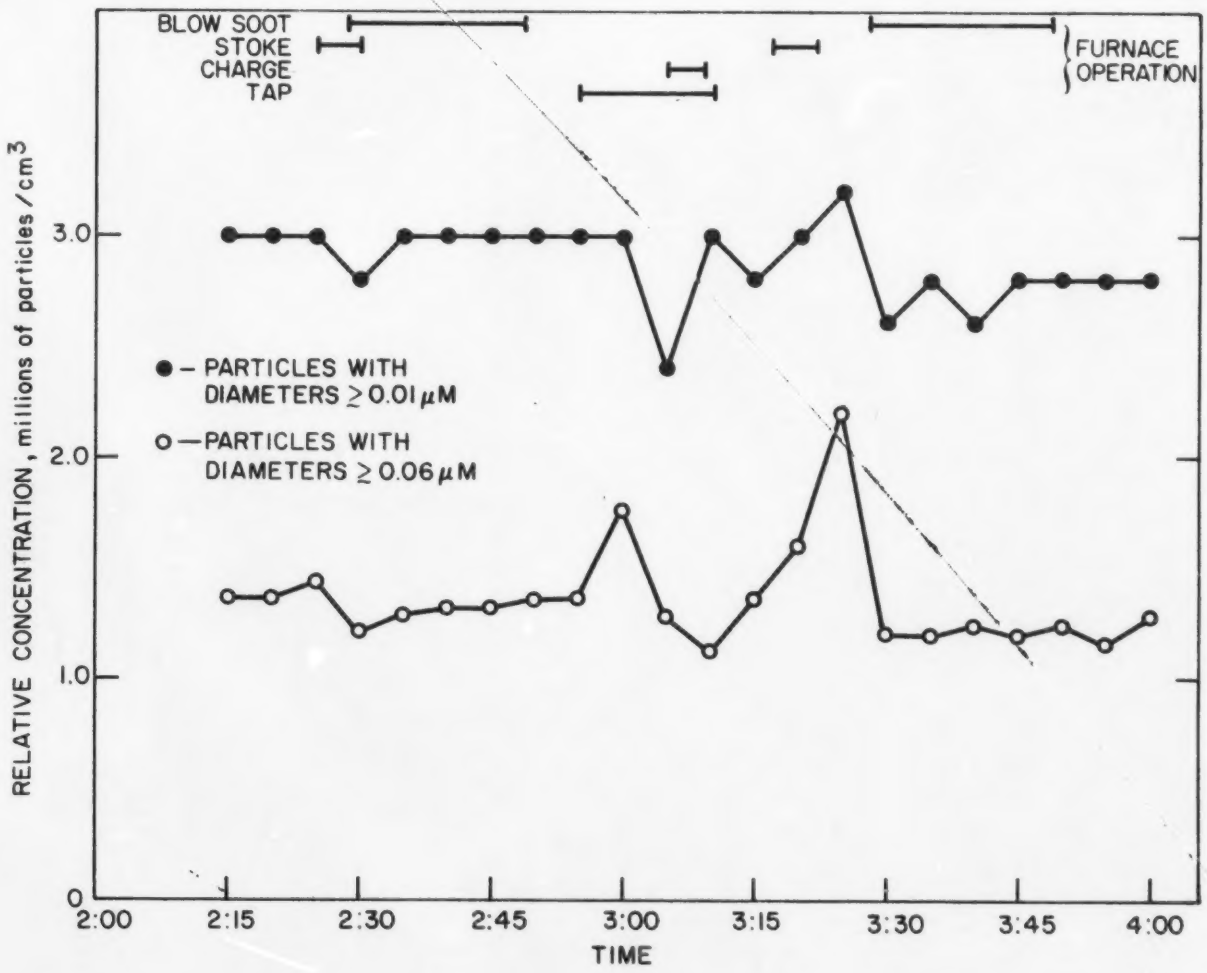


Figure 4. Inlet condensation nuclei counter data (with diffusion batteries) through a typical set of furnace operations.

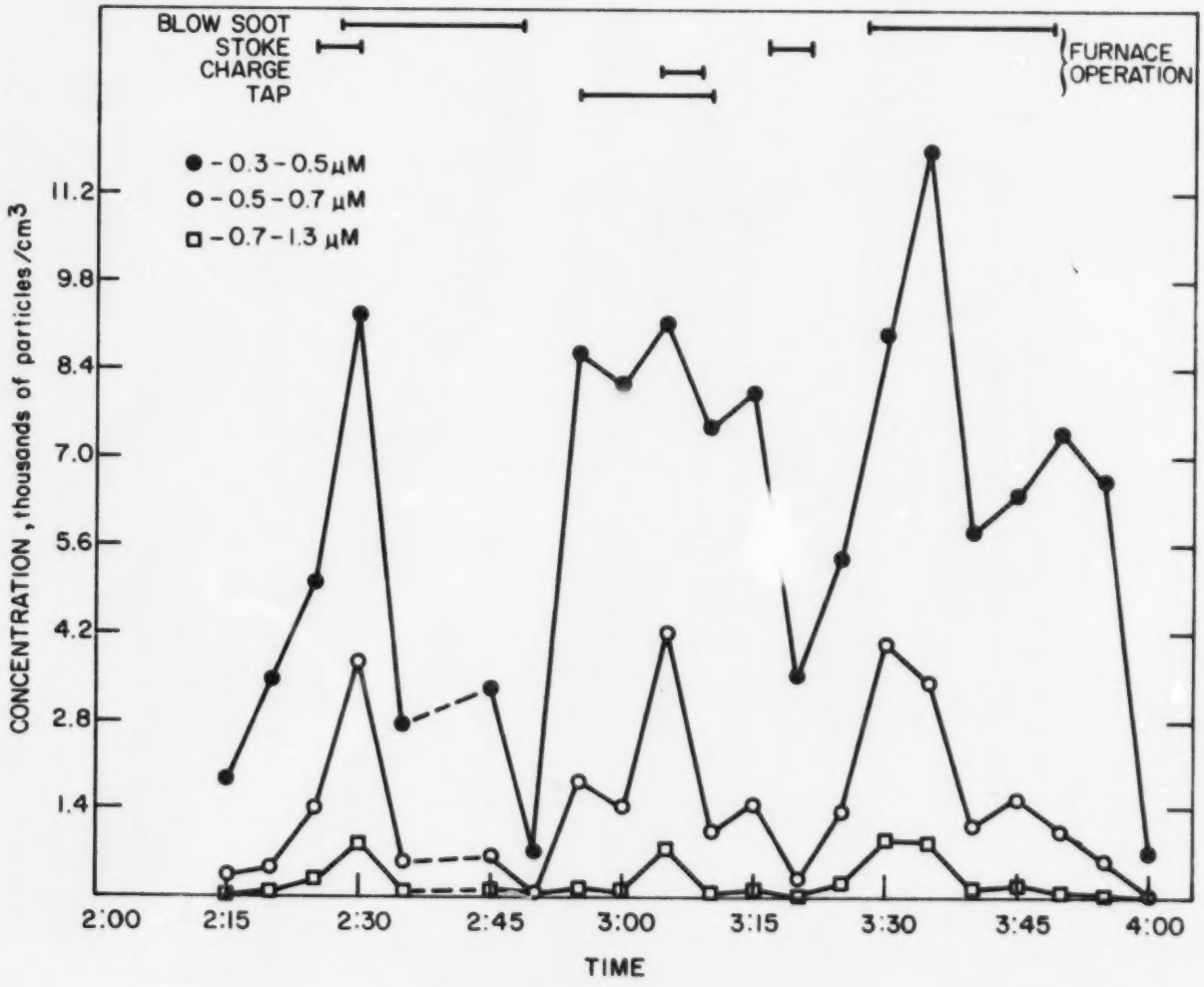


Figure 5. Inlet optical particle counter data through a typical set of furnace operations.

cycle. Figure 5 shows data from the particle counter over the same time span. It is evident from Figures 4 and 5 that large variations in the particulate concentration and size distribution occur, and that these variations can generally be traced directly to one of the major furnace operations. The accuracy of the fractional efficiency results were thus limited by the degree to which appropriate inlet and outlet time averages could be obtained.

Figure 6 shows typical averaged inlet and outlet size distributions as obtained by optical and diffusional methods over approximately one furnace cycle. Figure 9 shows the fractional efficiencies calculated from these data together with results from the impactor measurements. (In Figure 9, the impactor data is presented using particle diameters based on particle densities of 4.5 grams/cm^3.)

Inertial sizing was accomplished using Brink Cascade Impactors for inlet measurements and Andersen Impactors for outlet measurements. Sampling was done at near isokinetic rates. Errors due to deviations from isokinetic sampling should be of little consequence for particles having aerodynamic diameters smaller than 5 μm. Because of the relatively small duct dimensions and the relatively fine particulate being sampled, single point sampling was used. The inlet impactor runs were made using extractive sampling with the impactors operated in an oven at a temperature of 408°K (275°F). The outlet impactor samples

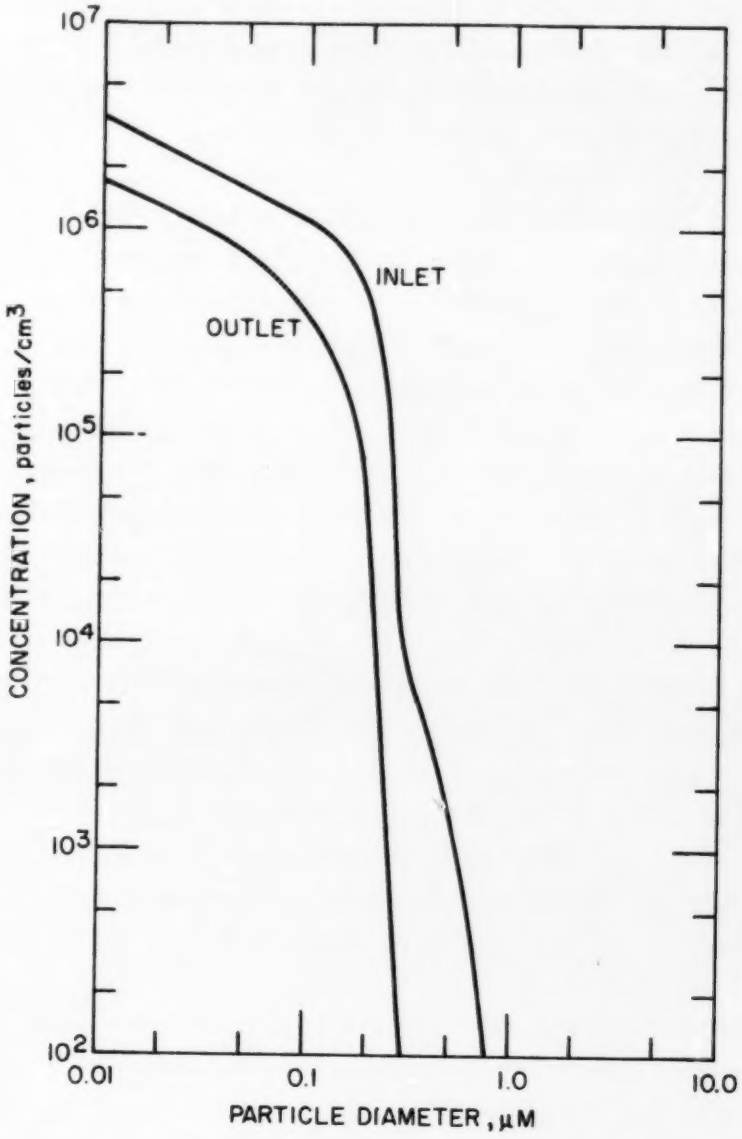


Figure 6. Average inlet and outlet size distributions on a cumulative concentration basis.

were obtained in-situ with the impactors heated to about 22°K (40°F) above flue gas temperature to insure that no condensation took place within the impactor. Such condensation might cause operational difficulties or lead to incorrect sizing.

Because of the wide disparity in the inlet and outlet mass loadings (inlet ∿ 500-3800 mg/DSCM (0.220-1.660 grains/DSCF) and outlet ∿ 10 mg/DSCM (.005 grains/DSCF), complete simultaneity in the inlet and outlet sampling was not possible. Outlet samples were generally of about 8 hours duration while inlet samples were of about 5 minutes duration. Because of the low outlet loading and the consequent length of the outlet sampling time, it was found to be impractical to attempt to isolate a single furnace cycle; however, an attempt was made to have all outlet samples cover an integral number of furnace cycles. Because the inlet sampling could not correspond directly with the outlet sampling, an average inlet mass loading for one complete furnace cycle was synthesized for each size interval covered by the inlet impaction stages from a total of 30 runs made over the four-day period of June 25-28.

The sizes reported here for the inertial data are given in two forms, "aerodynamic" and "physical" diameters. The "physical" diameters are based on an assumed particle density of 4.5 gm/cm^3. If the true particle densities are lower than this value, the

sizes as given should be increased by a factor equal to the square root of ratio of the assumed density to true density. Aerodynamic diameters are diameters based on a particle density of 1 gm/cm^3. The impactor data are summarized in Tables I and II. Figure 7 shows the averaged inlet mass size distribution on a cumulative percentage basis for both aerodynamic and physical sizes. The fractional efficiencies as calculated from these data are shown in Figure 8 on an aerodynamic diameter basis and in Figure 9 on a physical basis.

Because the scrubber water used in this application is in a recirculating loop, a substantial buildup of dissolved solids occurs in the water. Any evaporation of scrubber droplets to sizes that will escape the cyclonic mist eliminator will contribute to the exit particulate, perhaps to a substantial degree. During the tests described in the previous sections of this report, the dissolved solids content of the scrubber water was about 750 ppm. At this solids concentration, a 1% loss of scrubber water from the mist eliminator would result in an exit particulate loading of approximately 6 mg/M^3 (or about .003 $grains/ft^3$). In an attempt to determine the extent of the actual contribution of evaporative residues from the scrubber water to the exit particulate loading, two outlet impactor runs were made on November 26, 1974. For these runs the scrubber was operated in a single pass water usage mode with water having a dissolved solids content of about 230 ppm. Exit particulate loadings as functions of particle size for this second test are included in Table II. Although

TABLE I

SCRUBBER INLET LOADING BY SIZE INTERVAL

Date	Time	Furnace Operations	Particulate Loading mg/DSCM	Dia., μm ρ = 4.5	Loading In Size Interval, mg/DSCM >5.9	3.4-5.9	2-3.4	1.4-2.0	0.7-1.4	0.39-0.70	0.2-0.5	<.2
6/25	09:05*	Tap	1300		79	18.9	22.4	31.3	89.5	224.	355.	480.
	11:16*	Tap	3760		373	318	410	371	480	583	323	901
	12:24*	Normal	474		130	19.9	21.5	33.0	69.3	41.2	101	57.7
	14:59	Normal	1595		1090	105	82.4	49.4	49.4	54.9	49.4	116
	15:25	Stoke	812		263	205	92.4	69.3	26.3	33.0	69.3	52.8
	16:52	Tap	1500		300	252	13.3	98.8	350	162	238	89
	18:00	Charge	841		170	165	154	82.4	43.9	30.2	124	71.4
6/26	09:37	Normal/ Charge	617		129	42.8	26.3	33.0	33.0	65.9	132	155
	11:10	Tap	1830		901	129	79.2	208	76.0	241	99.1	99.1
	11:50	Normal	155		39.6	<2	6.6	<2	<2	<2	29.7	79.2
	12:05	Normal	891		403	56.1	39.6	33.0	64.9	76.0	89.0	129
	14:20	Normal	399		162	13.2	16.5	22.9	22.9	33.0	62.7	65.9
	15:26	Normal	848		366	82.4	33.0	19.8	16.5	29.7	75.9	224
	16:25	Charge	848		95.6	99.1	99.1	33.0	33.0	109	254	125
	17:15	Tap	967		234	109	29.7	43.0	135	99.1	237	79.2
6/27	10:07	Charge	627		85.8	39.6	29.7	33.0	75.9	112	125	125
	10:40	Normal/ Stoke	706		76.0	49.4	33.0	12.7	33.0	396	42.9	62.7
	11:38	Normal	551		257	52.9	26.3	16.5	26.3	82.4	16.5	72.5
	13:09	Tap	1600		245	711	36.4	29.7	46.2	76.0	323	129
	14:18	Charge	868		371	185	39.6	16.5	29.7	39.6	46.2	142
	15:02	Tap	1690		961	149	52.8	89.0	49.4	152	139	99.1
6/28	09:09	Tap	987		641	59.5	46.2	19.8	26.3	29.7	89	76.0
	10:24	Charge/ Stoke	271		92.4	9.9	16.5	13.3	19.8	13.3	26.3	79.2
	11:02	Tap	614		277	89.3	46.2	19.8	26.3	33.0	69.3	72.6
	12:11	Stoke	980		364	185	102	139	56.1	52.8	52.8	29.7
	13:15	Normal/ Tap	439		109	36.4	26.3	16.5	16.5	39.6	99.1	95.6
	14:29	Stoke	1670		1144	281	26.3	13.3	36.4	33.0	46.2	89.0
	15:02	Tap	1790		1300	191	26.3	36.4	39.6	42.9	76.0	79.2
	16:16	Charge	406		33.0	139	29.7	16.5	33.0	36.4	36.4	82.4
				Dia., μm ρ = 1	>13	7.2-13	4.3-7.2	3.0-4.3	1.6-3.0	1.2-1.6	.5-1.2	<.5
	WEIGHTED PROCESS AVERAGE		577		199	61.8	29.7	27.5	34.3	57.2	75.5	91.5

*Measurements made on furnace #22 (identical to furnace #23, running same product).

TABLE II

SCRUBBER OUTLET LOADING BY SIZE INTERVAL

Date	Start Time	End Time	Dia., μm ρ = 4.5	Loading In Size Interval, mg/DSCM >7.5	5.2-7.5	3.2-5.2	2.2-3.2	1.5-2.2	.65-1.5	.39-.65	.27-.39	<.27
6/26	09:00 10:40	10:00[T] 17:40		.39	.21	.11	.14	.23	.34	.50	.85	14.9*
6/26	14:00	18:30		.41	.25	.34	.25	.30	.32	.53	.76	5.63
6/27	09:30	17:00		.39	.30	.34	.34	.41	.50	.69	1.01	6.73
6/27	10:00	17:30		.46	.25	.32	.27	.32	.37	.59	.85	5.45
6/28	09:15 10:55	10:25[T] 17:50		.39	.32	.34	.37	.37	.55	.64	.92	7.18
6/28	09:55 10:55	10:25[T] 18:15		.32	.32	.30	.32	.32	.48	.78	1.14	6.86
11/26	11:04 11:10	18:04 18:10		.19 .53	.20 .48	.13 .37	.27 .41	.28 .39	.82 1.15	2.80 3.65	3.63 4.73	9.65 13.90
			Dia., μm ρ = 1.0	>15.8	11.1-15.8	6.9-11.1	4.9-6.9	3.2-4.9	1.5-3.2	.92-1.5	.67-.92	<.67

*Loading may be atypical as a result of a power outage at about 10:00 am. Impactor run may have resumed before the scrubber had attained steady state operating condition.

[T]Interrupted because of plant power outage.

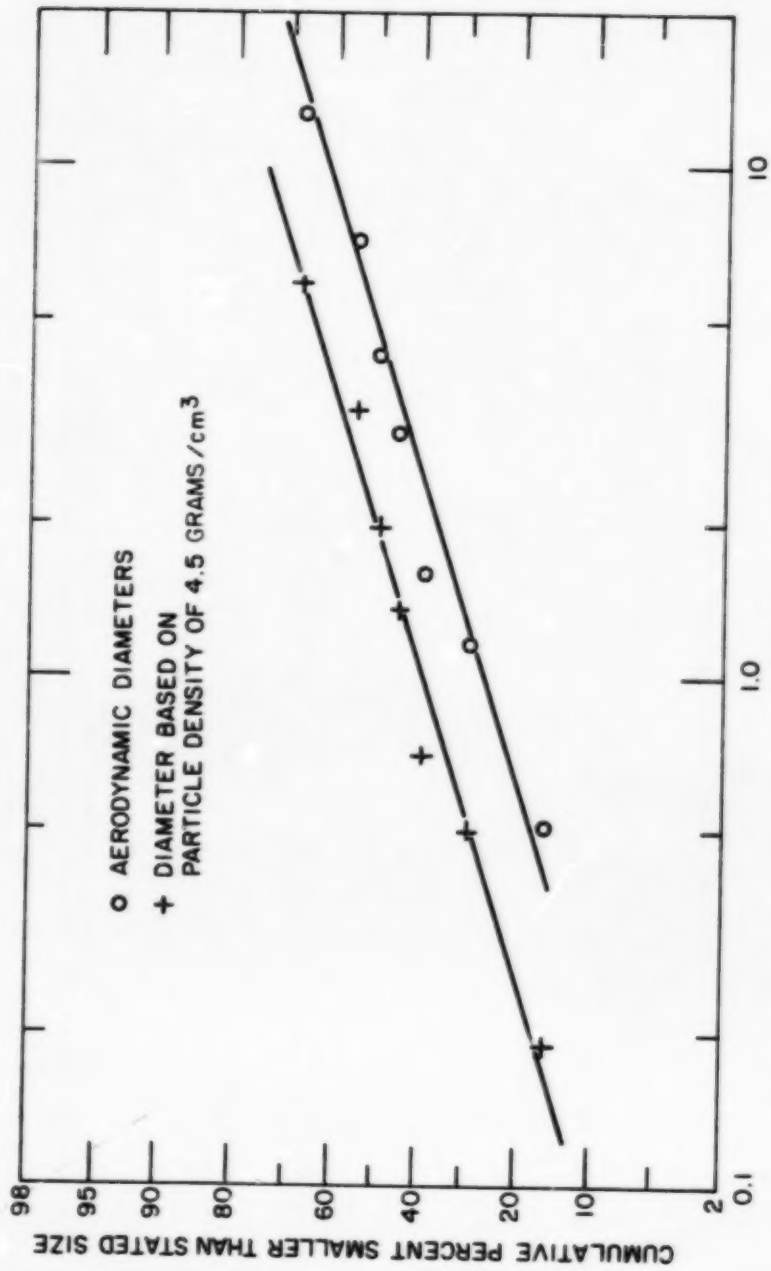


Figure 7. Average inlet size distribution on a cumulative weight percentage basis.

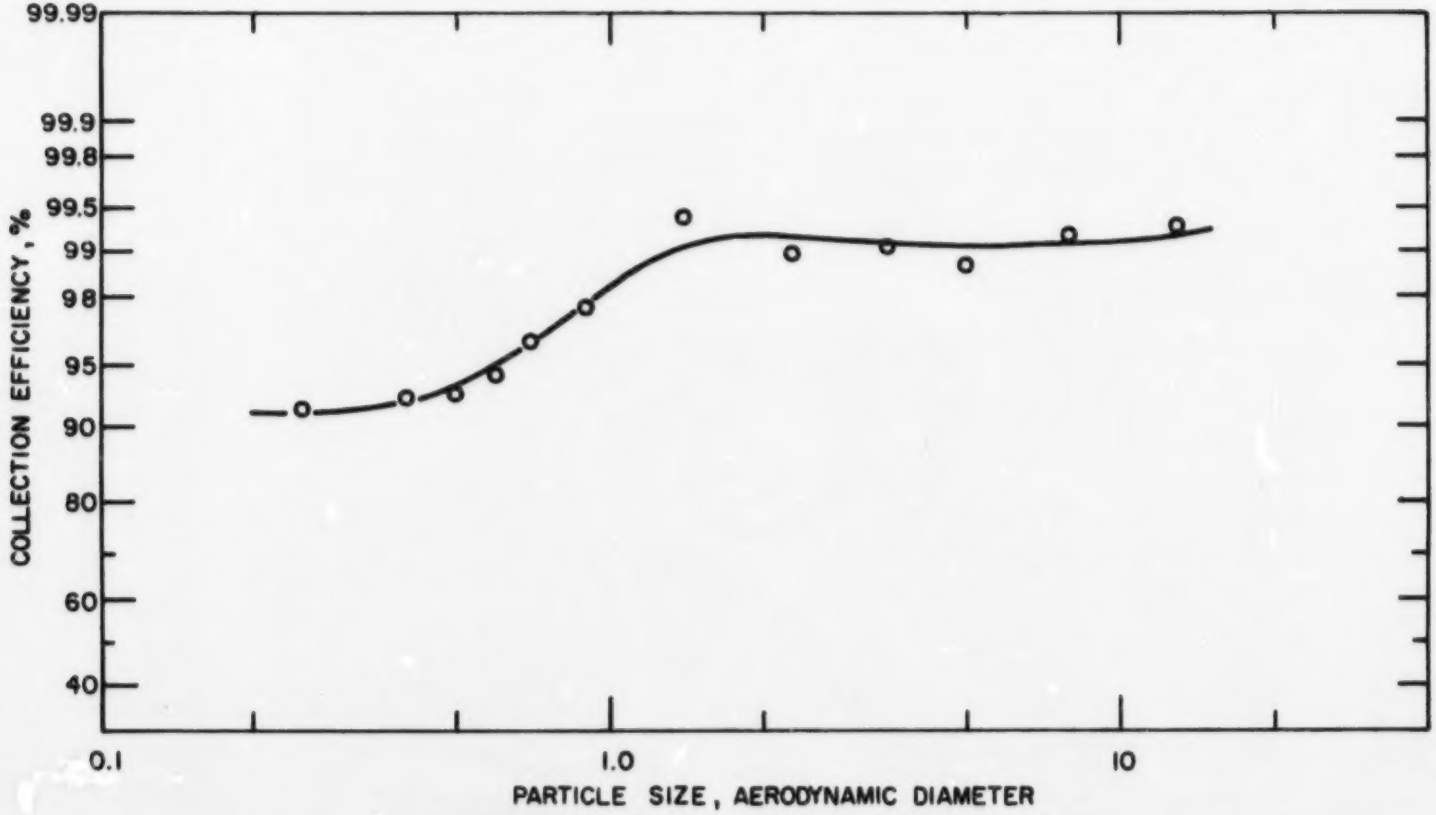


Figure 8. Fractional efficiency of the Aronetics Wet Scrubber calculated from the weighted averages of 30 inlet (Brink) and 6 outlet (Andersen Mark II) Impactor tests. Particle sizes are given as aerodynamic diameters (density = 1 gm/cm^3).

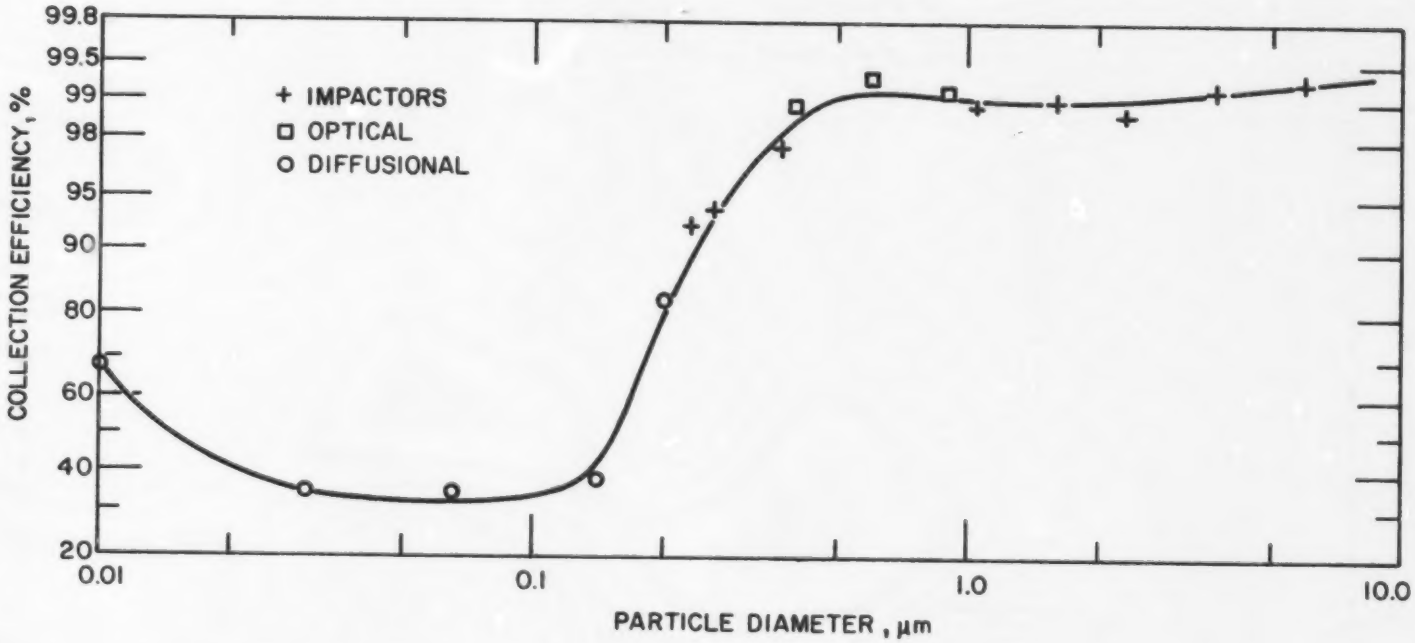


Figure 9. Fractional efficiency of the Aronetics Scrubber based on optical, diffusional, and impactor data.

the furnace product was nominally the same for the November 26 tests as that during the previous tests, the furnace raw material and product compositions were somewhat different. (The various raw material and product compositions are given in Appendix B.)

Plant personnel stated that the furnace was upset on this test (November 26) and that as a result of past experience they would expect the inlet loading to the scrubber to be higher during these tests than during the previous test series. Unfortunately, time and circumstances precluded inlet measurements during this short second test period. And as a further complication, the scrubber manufacturer stated that a perforated inner liner of the mist eliminator had become plugged in the interval between the two sets of tests, resulting in a partial malfunction of the mist eliminator. Because of the combination of these various factors, it is felt that this brief second test did not accomplish the intended goal and that the data, although of some interest, does not represent a valid comparison of the effect of dissolved solids in the scrubber inlet water on the exit loadings of the system.

Mass train measurements were obtained by Guardian Systems, Inc., Anniston, Alabama, under subcontract to Southern Research Institute on June 28 and 29, and the results of these measurements are shown in Table III. The overall efficiencies, by mass, based on these results are included in Table III.

TABLE III

MASS TRAIN (METHOD 5) RESULTS

Position	Inlet	Inlet	Inlet	Inlet	Outlet	Outlet
Date	6-26-74	6-26-74	6-27-74	6-27-74	6-26-74	6-27-74
Test No.	1	2	3	4	5	6
Time Start	1045	1504	0915	1302	1047	0915
Duration, min.	180	180	180	180	360	360
Avg. Gas Temp, ^{o}K	894	894	894	894	334	337
^{o}R	1610	1610	1610	1610	601	607
Moisture, Vol. %	4.18	3.39	5.33	3.41	22.87	20.42
Avg. Gas Velocity, M/sec	20.59	20.56	18.68	21.01	5.05	3.36
Sample Vol. at Stack Conditions, M^3	7.01	7.03	8.33	8.39	10.06	9.00
Sample Vol. at Dry Std. Conditions, M^3	2.21	2.24	2.60	2.67	6.88	6.29
Grams/ACM	.117	.181	.174	.130	.016	.011
Grams/DSCM	.366	.570	.554	.410	.023	.016
Grains/DSCF	.160	.249	.242	.179	.010	.007
Efficiency					95.1	96.7

Appendices are included which contain summaries of furnace and scrubber operations during the time intervals over which data were obtained, and cost-estimates for the operation of the scrubber.

SECTION IV - APPENDICES

APPENDIX A

MANUFACTURERS DESCRIPTION OF THE ARONETICS TWO-PHASE JET SCRUBBER

A pressurized, heated, liquid when passed through a properly designed nozzle will produce a two-phase mixture of vapor and liquid droplets that is an excellent cleaning medium. The droplets can be accelerated to extremely high velocity as a result of the expansion force created by a portion of the liquid being converted to vapor. The general configuration of this type of scrubber is shown in Figures Ala and Alb. The proper arrangement of components allows a draft to be induced which eliminates or drastically reduces fan power requirements. The two-phase jet scrubber produces water droplet velocities which vary with the temperature of the scrubbing fluid as shown in Figure A2. It is Aronetic's experience that jet velocities in the range of 1000 feet per second are quite satisfactory for particulate removal in the size range down to 0.10 microns. The velocity in the region immediately downstream of the nozzle is probably substantially supersonic since there is considerable evidence that sonic velocity in a two-phase mixture may be as low as 350 feet per second. However, Aronetic's believes that inertial impaction is the controlling mechanism in cleaning and that the existence, or absence, of the shock phenomena associated with supersonic flow is not an advantage in the cleaning effectiveness. Thus, the velocity in feet per second

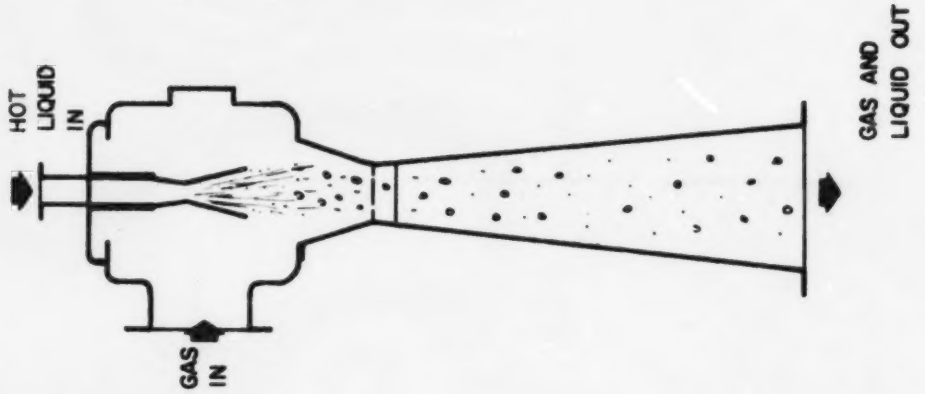


Figure Ala. Generalized Two Phase Jet Scrubber Nozzle.

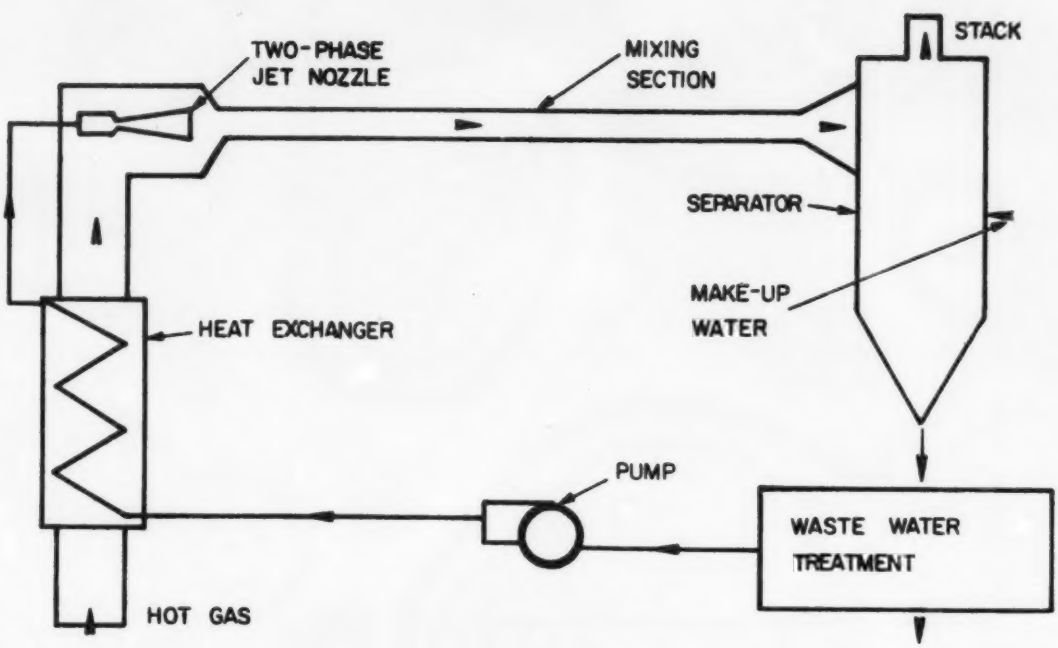


Figure Alb. Generalized Two Phase Jet Scrubber System.

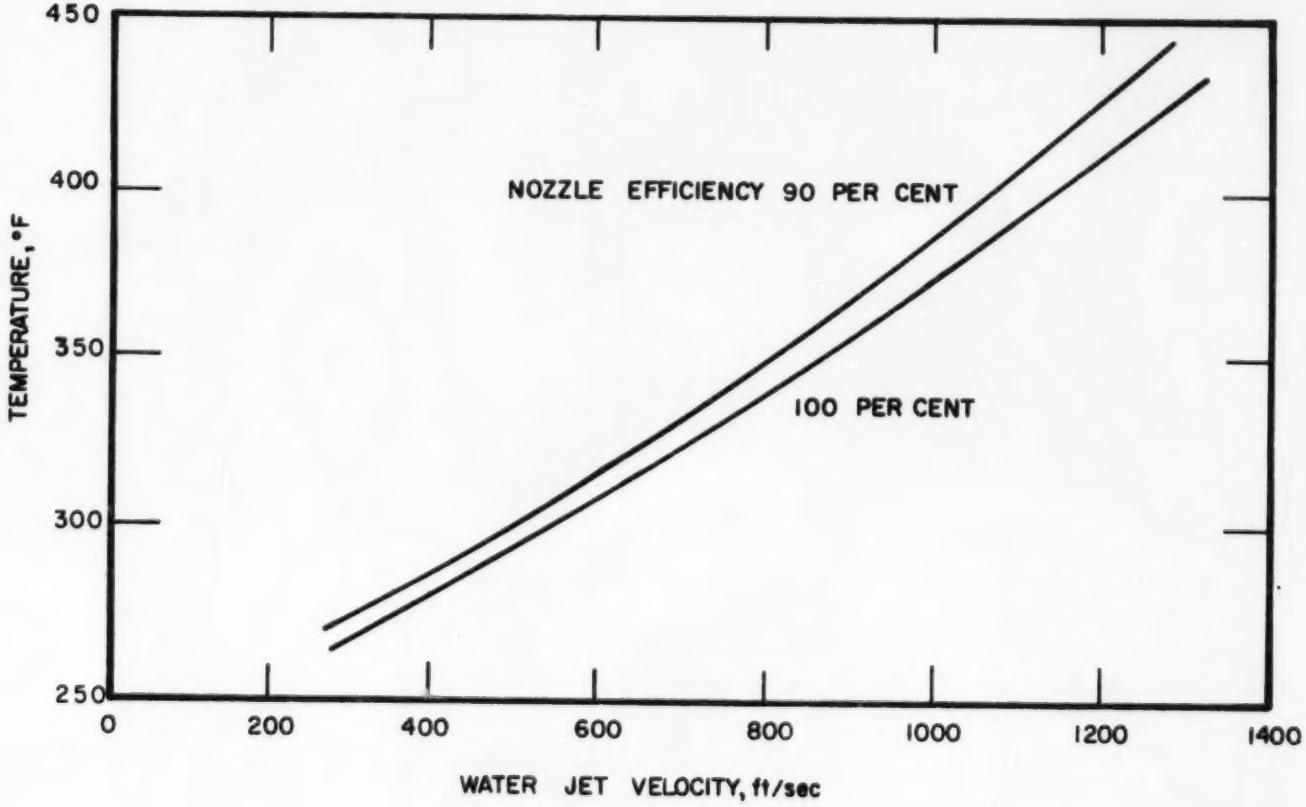


Figure A2. Variation of water droplet velocity from Two Phase Jet Nozzle with water temperature.

is the controlling parameter rather than the Mach Number, or relationship of velocity to the local speed of sound. The device operates at a very low noise level. The sound frequency and level is similar to that generated by a garden hose nozzle.

With respect to the draft producing capacity of this type of scrubber system, it should be evident that this is a pure momentum transfer mechanism; therefore, the amount of draft is a function of the amount of fluid passed through the nozzle and the degree to which this fluid is accelerated. The velocity is a function of initial water temperature, as shown in the previous figure. The effect of water flow rate on system pressure rise is shown in Figure A3 for water at a temperature of 400^{o}F. It should be emphasized that this is a rise in pressure across the scrubber and should not be confused with the pressure drop which is associated with the venturi type scrubber. In most applications, the pressure rise produced by the two-phase jet is sufficient to overcome the pressure drop in other components of a complete system.

The most direct application of the two-phase scrubbing system is in the control of emissions from processes which generate high temperature gas, laden with submicron particulate. Typical examples are the various metallurgical furnaces and processes. Figure A1b showed schematically the general arrangement of the components as tested in this report. An economizer type of heat exchanger is used to transfer thermal energy from the high temperature process exhaust gas to pressurized hot water which is delivered to the heat

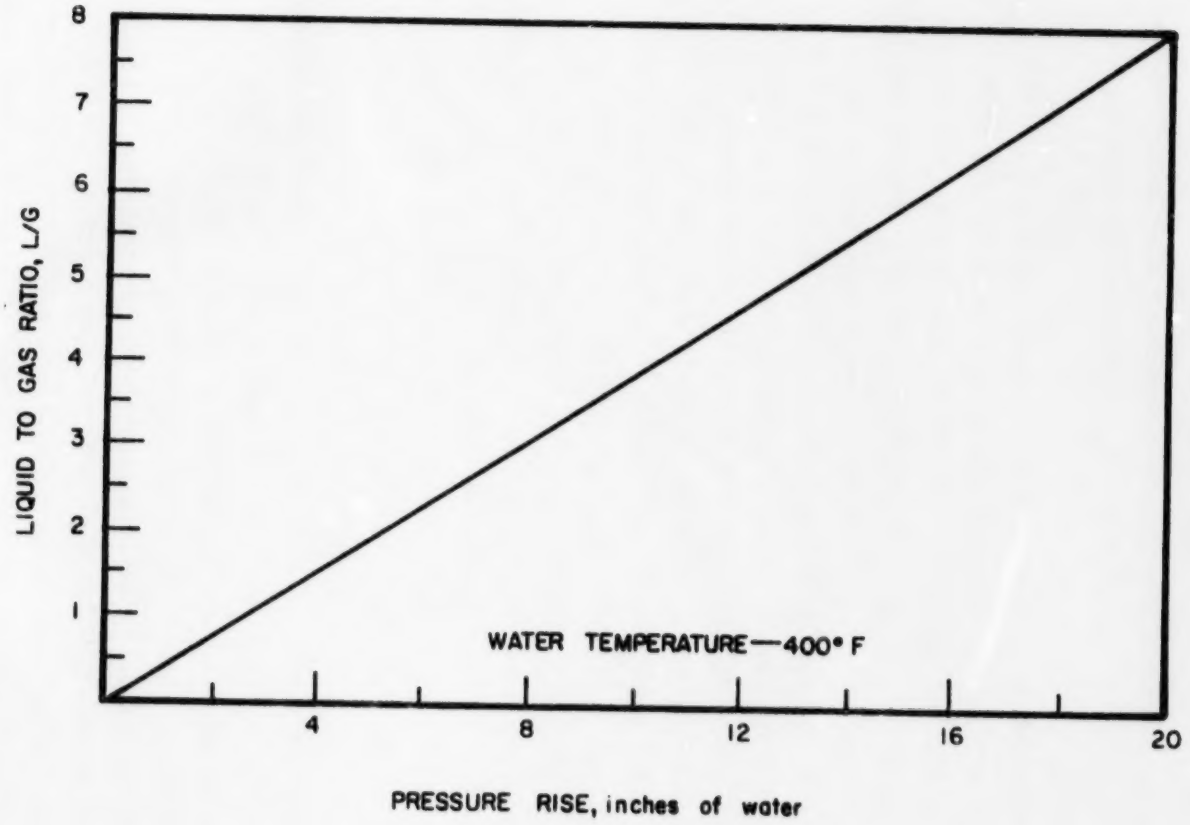


Figure A3. System pressure rise as a function of water flowrate.

exchanger by a pump. Water exiting the heat exchanger is delivered directly to the nozzle in its liquid state. For most applications, the water temperature is approximately 400°F and the water pressure is approximately 350 psi, or high enough to ensure that the fluid remains in the liquid state until it has passed the nozzle throat. A properly dimensioned mixing section must be provided for intimate contact between the accelerated water droplets and the particle laden gas. The final component in the scrubbing system train is a separator which will remove the dirty water droplets and allow the clean gas to be discharged. Water drained from the separator is passed to water treatment equipment which may be used to remove substances scrubbed from the gas and to prepare the scrubbing liquid for recycling. In the present instance, the water is used for approximately three passes through the system before final discharge.

If the process off-gas is at a temperature level above 1200°F, an additional option becomes available in the selection of components. The economizer type of heat exchanger may still be used to deliver heated water directly to the nozzle, or a steam boiler may be used as an intermediate step in the heating of water. If sufficient energy is contained in the gas, it is possible that a quantity of steam may be produced which is greater than the demands of the scrubber. This steam is then available for other possible plant applications. Other elements of the system remain essentially the same with the exception of the addition

of a method to transfer thermal energy from steam to water. The choice between the steam boiler and the economizer type of system for the very high temperature gases is dictated by local conditions at the site in question.

APPENDIX B - FURNACE OPERATION AND PRODUCTION DATA

Date/Time	Raw Materials: ORE kg / lbs.	COKE kg / lbs.	REMELT kg / lbs.	GRAVEL kg / lbs.	Product: Kg / lbs.	Ferrochrome Product Analysis: % Chrome	% Silicon	% Carbon	Furnace Load: KW
6/25 12-8	25720	4285	3810	1525	7260				
	56700	9450	8400	3360	16000	70.3	.71	7.0	7680
8-4	31840	7890	4715	1890	8030				
	70200	17400	10400	4160	17700	71.0	.44	7.1	7740
4-12	22045	4900	3265	1305	4620				
	48600	10800	7200	2880	10190	70.3	.57	7.6	7380
6/26 12-8	20820	4900	3810	1525	11195				
	45900	10800	8400	3360	24680	70.4	.48	7.1	7300
8-4	35515	7890	5260	2105	9895				
	78300	7400	11600	4640	21810	70.3	.43	6.8	7920
4-12	29395	6895	8435	1740	7260				
	64800	15200	18600	3840	16010	70.4	.87	7.0	6660
6/27 12-8	19600	4500	2905	1160	11045				
	43200	9920	6400	2560	24350	70.7	.71	6.9	7560
8-4	42865	10450	6350	2540	9680				
	94500	23040	14000	5600	21340	68.5	.89	6.2	7380
4-12	26945	6285	3990	1795	10505				
	59400	13860	8800	3960	23160	69.0	.80	6.9	7200
6/28 12-8	30620	7145	4535	2040	8295				
	67500	15750	10000	4500	18290	70.7	.89	6.7	7380
8-4	28270	6570	4175	1880	21005				
	62100	14490	9200	4140	46310	69.9	1.06	6.8	7330
4-12	17145	4770	2540	1145					
	37800	10520	5600	2520	None	--	--	--	6988
11/26 12-8	28223	7742	4355	980	10584				
	62217	17067	9600	2160	23333	65.7	2.37	6.7	7377
8-4	28223	7742	5443	980	10584				
	62217	17067	12000	2160	23333	66.7	1.71	7.0	7377
4-12	28223	7742	3085	980	10584				
	62217	17066	6800	2160	23334	64.6	2.49	6.6	7377

APPENDIX C - SCRUBBER OPERATING PARAMETERS

	Water Flow (l/min)	Water Inlet Temp. (^{o}K)	Water Exit Temp. (^{o}K)	Air Inlet Temp. (^{o}K)	Air Exit[T] Temp. (^{o}K)	Air Flow (Kg/min)	
25th							
1200	204.4	316.3	469.1	860.8	377.4	250.9	
1230	174.3	316.3	488.6	844.1	374.7	248.2	
1300	147.8	316.3	488.6	844.1	371.9	209.1	
1330	166.8	316.3	491.3	871.9	374.7	227.7	
1400	185.7	316.3	494.1	877.4	380.2	257.7	
1430	176.2	316.3	488.6	849.7	377.4	249.5	
1500	182.8	316.3	496.9	888.6	383.0	253.6	
1530	187.4	316.3	496.9	883.0	383.0	263.2	
1600	164.7	316.3	494.1	849.7	377.4	240.9	
1630	176.0	316.3	494.1	877.4	377.4	243.2	
Daily Average	176.4 ± 15.0	316.3	490.2 ± 8.4	864.7 ± 17.2	377.4 ± 3.3	244.5	
26th							
0900	202.5	310.8	466.3	838.6	377.4	266.4	
0930	174.1	310.8	458.0	827.4	360.8	214.1	Not Sampling
1000	181.7	310.8	471.9	858.0	366.3	232.3	
1030	170.3	310.8	485.8	888.6	369.1	223.6	
1100	182.8	310.8	499.7	880.2	377.4	267.7	
1130	193.0	310.8	499.7	896.9	383.0	276.8	
1200	196.8	310.8	499.7	896.9	388.6	285.5	
1230	179.8	308.0	498.0	877.4	385.8	270.9	
1300	160.1	308.0	494.1	885.8	377.4	256.8	
1330	168.4	308.0	499.7	860.8	377.4	260.5	
1400	174.9	308.0	499.7	863.6	380.2	270.5	
1430	172.2	308.0	498.0	880.2	377.4	253.6	
1500	196.8	308.0	502.4	910.8	385.8	284.5	
1530	168.4	308.0	502.4	871.9	377.4	258.2	
1600	155.2	308.0	494.1	844.1	371.9	238.6	
1630	151.4	308.0	499.7	866.3	369.1	227.7	
1700	159.0	308.0	502.4	866.3	374.7	245.5	
1730	136.3	308.0	502.4	844.1	366.3	216.4	
1800	138.2	308.0	502.4	844.1	366.3	219.5	
1830	159.0	308.0	485.8	855.2	358.0	221.8	
Daily Average	171.1 ± 18.9	309.0 ± 1.1	493.0 ± 13.3	867.9 ± 22.0	375.2 ± 7.2	249.5	

[T]Heat exchanger exit.

	Water Flow (l/min)	Water Inlet Temp. (°K)	Water Exit Temp. (°K)	Air Inlet Temp. (°K)	Air Exit Temp. (°K)	Air Flow (Kg/min)	
27th							
0900	212.0	319.1	488.6	877.4	408.0	281.8	
0930	162.8	319.1	499.7	866.3	391.3	241.4	
1000	159.0	321.9	505.2	844.1	388.6	249.5	
1030	155.2	321.9	505.2	849.7	388.6	240.9	
1100	168.4	321.9	505.2	888.6	396.9	245.0	
1130	166.5	321.9	499.7	838.6	391.3	258.2	
1200	174.1	319.1	502.4	844.1	394.1	276.8	
1230	187.4	319.1	502.4	877.4	396.9	278.6	
1300	179.8	316.3	502.4	866.3	396.9	278.2	
1330	173.0	316.3	503.6	866.3	391.3	265.9	
1400	168.4	313.6	502.4	866.3	392.4	261.8	
1430	170.3	313.6	505.2	871.9	388.6	263.6	
1500	179.8	313.6	499.6	877.5	391.3	268.6	
1530	162.8	310.8	502.4	863.6	385.8	254.5	
1600	174.1	310.8	502.4	877.4	385.8	264.5	
1630	174.1	310.8	500.8	888.6	383.0	255.5	
1700	172.2	310.8	499.7	883.0	385.8	255.0	
1730	--	--	--	--	--	--	
1800	--	--	--	--	--	--	
1830	--	--	--	--	--	--	
Daily Average	173.0 ± 11.4	316.3 ± 4.4	501.3 ± 3.9	869.1 ± 17.8	391.3 ± 6.1	260.5	
28th							
0900	159.0	313.6	494.1	871.9	371.9	224.1	
0930	159.0	313.6	499.7	855.2	374.7	240.0	
1000	172.2	313.6	438.6	710.8	360.8	240.0	Not Sampling
1030	155.2	313.6	474.7	885.8	360.8	185.9	
1100	162.8	313.6	499.7	869.1	377.4	240.5	
1130	151.4	313.6	499.7	860.8	374.7	225.5	
1200	153.3	310.8	499.7	855.2	377.4	235.5	
1230	159.0	310.8	499.7	871.9	374.7	234.5	
1300	170.3	308.0	500.8	880.2	377.4	253.6	
1330	155.2	308.0	499.7	866.3	374.7	235.0	
1400	166.5	308.0	498.0	869.1	374.7	248.6	
1430	162.8	308.0	499.7	877.4	374.7	240.9	
1500	151.4	308.0	499.7	860.8	371.9	230.9	
1530	151.4	308.0	499.7	871.9	366.3	223.2	
1600	157.1	308.0	499.7	866.3	371.9	236.8	
1630	151.4	305.2	499.7	871.9	369.1	227.7	
1700	143.8	305.2	499.7	855.2	366.3	222.3	
1730	155.2	305.2	499.7	855.2	366.3	240.0	
1800	174.1	305.2	499.7	874.7	366.3	259.1	
1830	--	--	--	--	--	--	
Daily Average	158.6 ± 7.6	309.2 ± 3.3	495.8 ± 14.4	858.0 ± 37.8	371.3 ± 5.0	236.4	

APPENDIX D

ESTIMATED OPERATING COSTS OF THE ARONETIC'S TWO PHASE JET SCRUBBER SYSTEM

Data for these cost estimates were taken from Peters and Timmerhans, Plant Design and Economics For Chemical Engineers, 2nd edition, 1968, and are based on cost data for the year 1967.

	COST, $
Well Water	0.03 - 0.15/1000 gal.
River Water	0.02 - 0.06/1000 gal.
Fuel Oil	0.05 - 0.15/gal.
Electricity	0.02/KW-hour

Figure D1 shows estimated water use rates as furnished by Aronetics for achieving 99% cleaning efficiency for various particulate sizes. The use rate in the tests described in this report was approximately 6 gallons/1000 SCF.

The operating costs described here are based on two conditions - one in which the system energy is derived solely from process waste heat, and one for which fuel oil supplies the energy. These figures are estimates only and do not include such things as savings deriving from the fact that the system provides its own draft as well as that for the furnaces, consequently eliminating I.D. and F.D. fans, blowers, etc.

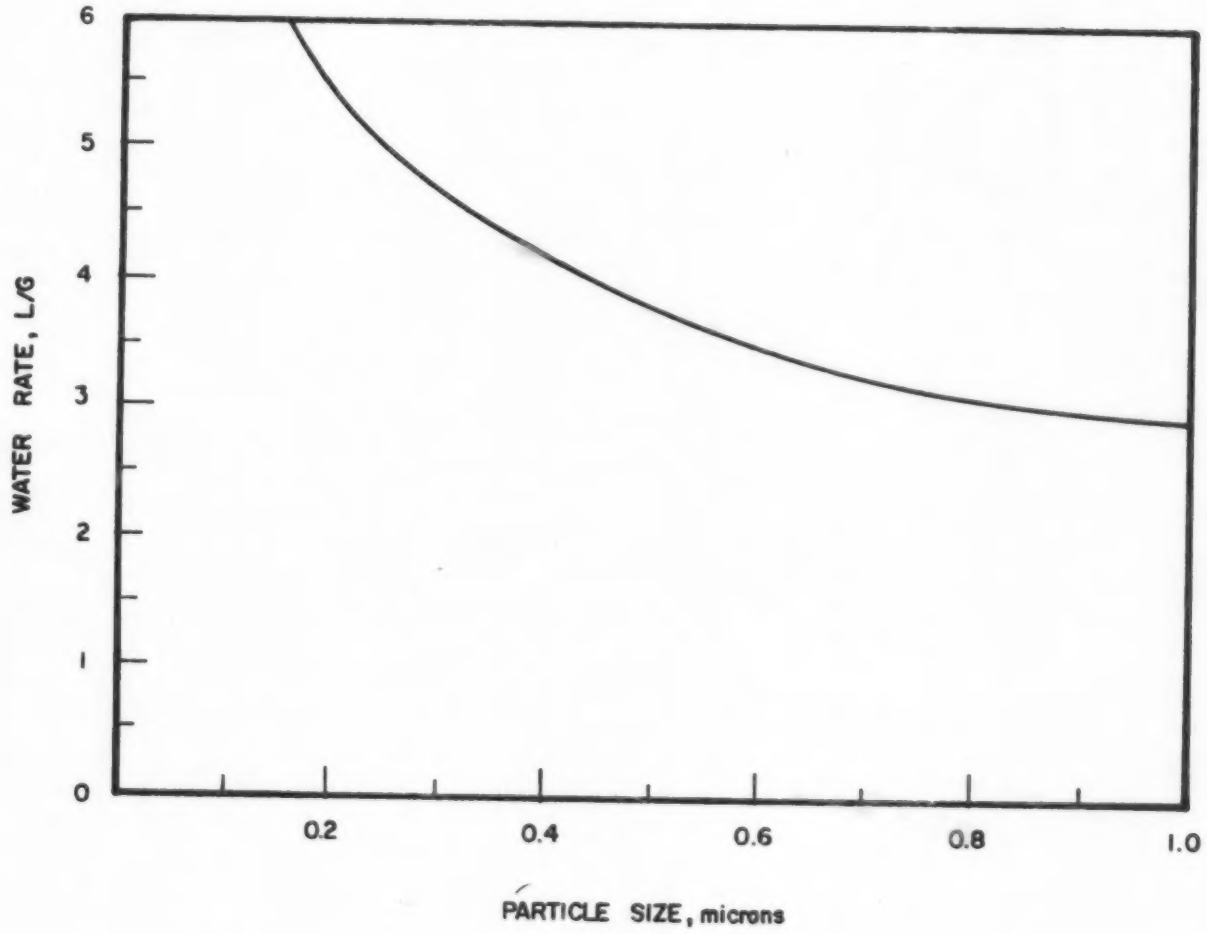


Figure D1. Water use rate required for achieving 99% cleaning efficiency for various particle sizes..

The conditions of the tests with a net pressure rise of 12½ to 16 in. H_2O were:

Water Usage	6 gal/1000 SCF
Cost of Electrical Power for pumps, etc.	.0017/1000 SCF*
Thermal Energy	17000 BTU/1000 SCF

Assuming nominal values for costs of 0.04/1000 gal. for water, and 0.08 gal. for fuel oil, with the fuel oil providing 150,000 BTU/gal., the operating cost per thousand SCF are .00024 for water and .0017 for electrical power for a total of .00194 when waste heat is used to drive the system. Where waste heat is not available for hot water production, adding the fuel cost of .0089/1000 SCF results in an operating cost per 1000 SCF of 0.0107. The annual operating costs per SCFM are $1.016 in the waste heat case and $5.59 for the case in which fuel must be purchased (excluding electrical energy - these values become 0.042 and 4.44, respectively.) For the purposes of the preceding operating cost estimates, amortization of capital costs were not included.

*Based on figures given in a paper by H. Gardenier at the APT/EPA 1974 Scrubber Symposium.